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Effects of three in-field water harvesting technologies on soil water content and maize yields in a semi-arid region of Zimbabwe

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ABSTRACT

Climate change and recurring mid-season dry spells have resulted in perennial droughts and poor yields in most smallholder farming areas located in marginal arid to semi-arid lands (ASAL) of Zimbabwe where they are dependent on rainwater for agricultural crop production. One approach that can be used to adapt to changing climatic pattern is in-field water harvesting. This study evaluated the soil profile water content and maize yields of 3 infield water harvesting technologies namely infiltration pits (IF), fanya juus (FJ) and contour ridges with cross ties (CRCT) in comparison to standard contour ridges (SC). The three systems are currently the focus of extension recommendations for water conservation in semi-arid regions of the country. Soil water content was measured on a regular basis using gravimetric methods at locations upslope and down slope of each structure. The average volumetric water content was signifcantly different between treatments, and it varied with increasing distance from the water harvesting structures. The average profile soil moisture content, over the three seasons were 8.3, 8.2, 8.1 and 7.8% for CRCT, FJ, IF and SC repectively. CRCT, FJ and IF retained more water for a greater distance from the harvesting structures compared to the SC. Maize yields were significantly higher in the water harvesting technologies compared to SC. Maize yields were 1196, 1164, 1250 and 749 kg ha^{-1} for CRCT, FJ, IF and SC respectively. There as a good correlation between water content and maize yields (R^2 = 0.80). It was concluded that improved water harvesting structures when compared to SC have the potential to increase maize yields in areas with water shortages, hence they can be a useful strategy for climate change adaptation.

1. Introduction

In Zimbabwe climate variability has affected marginal areas most as these areas generally receive low rainfall. Arid to semi-arid lands (ASAL) are more vulnerable to climate variability because in most cases the rainfall is not adequate to sustain dry land crop production. In addition, ASAL also have the least reliable rainfall distribution (Department of Meterological Services, 1981; Bratton, 1987) and there has been an increase in the average duration of intra-seasonal dry spells (New et al., 2006). Freqent droughts and mid-season dry spells that are common in most semi-arid regions often results in severe droughts and widespread food shortages (Nyamadzawo et al., 2013), and the most severe impacts are felt among the smallholder farmers. About 70% of Southern Africa estimated to be semi-arid, and the rainfall is erratic. Climate change predictions suggest Southern Africa will get drier and food insecurity is projected to increase as models predict 20–35% decreases in maize yields by 2030 (Lobell et al., 2008; New et al., 2006). Decreasing rainfall will worsen further the food security situation as most of the agricultural systems of southern Africa are predominantly rain-fed, with little to no irrigation backup in place (Camberlin et al., 2009).The FAOSTAT estimates puts the area under irrigation in Malawi at less than 3% of the country while in Zimbabwe it is less than 5% of the country. Only 11% (˜13000 ha (ha)) of the total irrigated land in Zimbabwe is found in the small-scale irrigation sector (FAO, 2000) and of this; only 6000 ha are currently in use whilst the remainder, 7000 ha, require major rehabilitation. In addition, putting up irrigation infrastructure has proven to be costly to make an impact on rural households' food security for most resource constrained countries (Nyamadzawo et al., 2013), hence there is need for efforts to develop climate smart rain-fed agriculture practices that can reduce the vulnerability of smallholder farmers who are found mostly in semi-arid regions. The use of in-field water harvesting represents such an opportunity of increasing crop production under rain-fed agriculture systems in the face of the current climate change phenomenon. A

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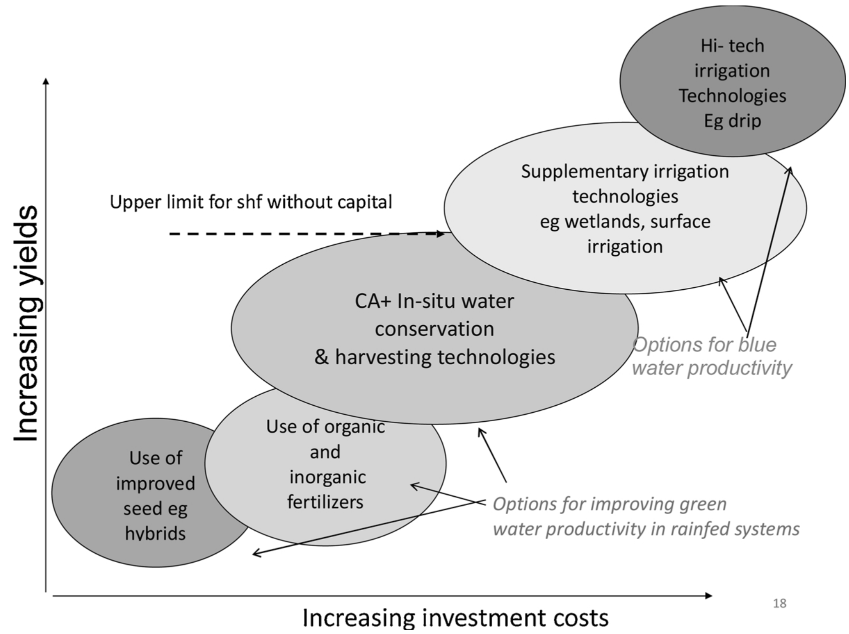

Fig. 1. A hypothetical illustration of options for improving agricultural water management in cropping systems. Adopted from Nyagumbo et al. (2009). Shf = smallholder farmers.

hypothetical model by Nyagumbo et al. (2009), suggest that besides using improved seed varieties, and organic and inorganic fertilizers, yields in the smallholder farming areas can be increased through the use of low cost water harvesting technologies (Fig. 1).

In-situ rain water harvesting, involves the use of methods that increase the amount of water stored in the soil profile by trapping or holding the rain when it falls, and it involves small movements of rainwater as surface runoff, in order to concentrate the water where it is required (UNEP, 1997). Ngigi et al. (2005) and Jebamalar and Ravikumar (2011) suggested that rain water harvesting involves the collection, storage and subsequent use of rainwater for domestic, agricultural and other livelihood activities where and when it falls. Though rainwater harvesting is a very old practice dating back to 4500 BCE in the Middle East and India, it has received little attention since the modernisation of agriculture (Sivanappan, 1997; Rockström, 2002; SIWI, 2001). With improved in-field water harvesting, harvested rainfall stored infield can possibly sustain crop production during the mid-season dry spells and it can be considered as a supplemental water source (Jebamalar and Ravikumar, 2011). In addition, rain water harvesting may also be considered as a key adaptation strategy to the impacts of climate change and variability (Barron et al., 2011).

Potential water harvesting techniques include the use of fanya juus (FJ), infiltration pits (IP) and contour ridges with cross ties (CRCT). These alternative methods of water conservation/harvesting are prefered to the standard contour ridges which were designed to safely dispose of run-off (Elwell and Stocking, 1988) instead of retaining it. The alternative water harvesting techniques came after the realisation that most of the rainfall received in ASAL is lost as runoff, and very little water is harvested for plant growth or future use and losses of > 50% of received rainfall have been reported (Nyamadzawo et al., 2012). High levels of runoff losses do not only limit water availability, but are also an erosion hazard as the runoff can cause nutrient loss (Elwell and Stocking, 1988).

These alternative in-field water harvetsing techniques can benefit farmers through (i) increased run-off retention thereby improving water availability to crops and (ii) reduced soil erosion through reducing water flow velocities and (iii) increased groundwater recharge through reduced run-off to natural water courses. However, the benefit usig CRCT, FJ and IF on soil water content and mazie yields of these structures has not been scientifically evaluated and quantified other than qualitative and positive indications from practising farmers. Therefore, the objective of this study is to evaluate the water conservation merits of usig CRCT, FJ and IF on profile water content and mazie yields in Shurungwi smallholder farming area of Zimbabwe. This study further explored factors driving or hindering the use of these water harvesting techniques by farmers in ASAL of Shurugwi.

2. Materials and methods

2.1. Soils of water harvesting experimental sites in Shurugwi Communal Lands

The study site was located in ward 5, Shurugwi district, Midlands province, about 70 km south-east of Gweru City. The study sites were located 19°59″ S, and between 30°16″ E and 30°18″ E.

2.2. Climate and vegetation

The experimental sites were located in Zimbabwe's agro-ecological zone IV where semi-extensive farming is practiced. Besides experiencing low total rainfall (450–650 mm), which is received between November and May (Fig. 2). Analysis of rainfall data for the study area showed that the three seasons when we carried out the study were within range of normal seasons. This region is subjected to seasonal droughts and severe dry spells during the rainy season. Highest temperatures of 38 °C are recorded in October while minimum temperatures (below 0 °C) are recorded in June. Main crops grown in this area are maize and groundnuts. Most of the natural vegetation has been cleared for agricultural purposes. However, *Parinari curatellifolia, Piliostigma thonninii, Ficus sp, Azanza garckeana* and *Strychnos* sp trees were dominant along contour ridges. Some re-growths of *Dichrostachys cinerea* and *Terminalia sericea* were mainly found on abandoned fields or uncultivated land. Exotic trees such as *Eucalyptus* spp. were also found close to homesteads and some uncultivated land.

2.3. Geology and soils

The area consists mainly of coarse textured soils (*Aerosols*) which

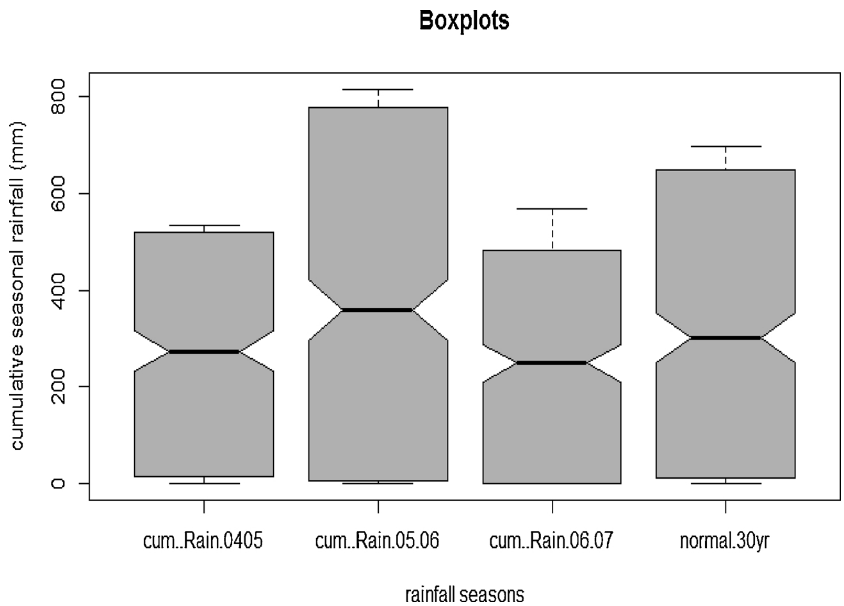

Fig. 2. Box plots for cumulative seasonal daily rainfall for each of the three seasons (2004/5–2006/7) in comparison to the 30-yr normal rainfall for the same location.

Table 1
Geographical locations and selected soil physical properties for the three study sites.

Site	Mukandabvute	Takara	Kuchicha
Grid Reference (UTM)	0214380; 7787803	0219151; 7786536	0218812; 7786733
Elevation	1072 m	1031 m	1045 m
Slope (%)	3 %	3	2%
Landuse	Maize	Maize	Maize
Effective Depth	70	63	70
Rainfall	450-650 mm	450-650 mm	450-650 mm
Parent Material	granite	granite	granite
% clay	3	2	2
% silt	4	4	7
%Sand	93	94	91
pH($CaCl_2$)	4.6	4.2	4.2
CEC	2.4	4.3	2.7
EC	90.6	194	102
% OC	0.47	0.35	0.34
P (ppm)	8	7	6
N (ppm) (Initial)	5	7	5

are derived from granitic parent material. Generally the soils in this area are moderately shallow to shallow (40 −100 cm) sands. A common feature of the soils is a stone line, consisting mainly of subrounded and rounded quartz stones, which overlies coarse grained soft weathering granitic parent material. Permeability of the soil is good to rapid throughout the whole profiles. These soils are well drained on crest and upper slope positions, however, the soils become moderately well drained to moderately poorly drained towards lower slope positions. These soils have high exchangeable potassium (K) and sodium (Na) and this is attributed to the granitic parent material. A summary of selected soil properties for the study sites are shown in Table 1.

2.4. Experimental layout

Three farm sites, each measuring at least 2.5 ha (ha) with a uniform average slope of 2 to 4% were selected. The sites were Mukandabvute, Takara and Kuchicha villages. The experiment was carried out for three seasons from 2004-2007. Season 1 was called the 2004/2005, season 2 was the 2005/2006 and season 3 was from 2006/2007. A detailed site characterization was conducted in June 2005 to identify and describe the nature of soils existing at each experimental site. Morphological properties of the soil such as depth, texture were assessed from pits dug in the experimental fields. Some chemical properties such as pH, C, N, CEC among others, were determined in the laboratory on soil samples taken from identified horizons of representative soil profiles (Table 1).

At each of the three sites, the fields were divded according to catena positions (upslope, mid-slope and lowerslope). At each catena position, three soil and water conservation treatments which were; (1) fanya juu, (2) Infiltration pit, (3) cross-tied graded contour ridge, were evaluated, and standard contour ridge which was the 4th treatment, was used as the control. Plots of 15 × 10 m in size were used. A completely randomised block design was employed, and all the treatments were replicated three times. The plots were planted to maize variety SC 513. Basal fertiliser was applied at a rate of 200 kg ha^{-1} at planting and ammonium nitrate (AN; 34% N) was applied at a rate of 120 kg ha^{-1} when maize was at knee height. These rates were used to mimic farmer practices and recommemdation by the extension serivices (Agritex).

2.5. Water harvesting structures

Most of the water harvesting structures are modification of the standard contour ridge. The standard contour ridge is found throughout Zimbabwe, and was enforced through 'The Native Land Husbandry Act of 1951' (Stockings, 1978). This act enforced the construction of contour ridges throughout the smallholder farming areas and enforced conservation and good farming practices with serious penalties for offenders. The standard contour ridges were constructed in a grade of 1:250, for a purpose of disposing off runoff water that caused soil erosion. Spacing varies depending on slope and soil type. The standard dimensions for a standard contour is 1.7 m for the channel and 1.7 m for the ridge (Dreyer, 1997). The standard contour ridge takes away about 15% of the total arable area out of production and this was not popular with smallholder farmers (Dreyer, 1997). It takes about 30 man days to construct contour ridges on 1 ha of land with an average slope as used in this study (2–4%), however, if the land is steep contour ridges will be closer, it may take even more time. In Zimbabwe, because contour ridges were constructed in the 1950s', what is currently required is to repair them, thus reducing the labour needs by between 50 and 70%.

CRCT, are a modification of the standard contour that was enforced in the 1950s'. Cross-ties are placed in the channel to reduce water flow velocity out of the channel to improve moisture conservation. Cross-ties

are placed at 10 m intervals depending on the main slope of the area and the expected runoff (Dreyer, 1997). Cross ties create a damming effect, thus converting standard contours from being water disposing structure, to water holding structures. It is relatively less costly to create cross tied on already existing contour structures. Labour requirements could be lower than that of infiltration pits hence they could a cheaper option provided their water retention ability proves equally effective.

Infiltration pits, are large are trenches dug along the contour ridge to trap run-off and increase infiltration and to hold water as it flows. This technique originated in Zimbabwe from a farmer called Mr Zephenia Phiri, in Zvishavane (Maseko, 1995). They are suitable for semi-arid regions and can be applied easily on land already with standard contours. The infiltration pits reduce runoff substantially, conserve moisture and can also be used for in-situ composting since the pits are placed along the contours and crop residues can accumulate in the pits from the fields above and below (Critchley, 1991; Hagmann, 1994). It is also less costly to make infiltration pits on already existing contour ridges, though they also require regular maintenance in terms of scooping out deposited soil. There are variation in dimension of infiltration pits, as no quantitative research data is available on the performance of the structures. Therefore no design specifications based on research are available. The most common are 1 × 1 × 1 m in dimension and are placed after every 10 m along the contour channel.

Fanya juus originated in Kenya and their construction involves throwing soil excavation from the drainage channel to the side of the channel. Fanya juus have been widely used in Ethiopia, Tanzania and Rwanda (Critchley, 1991; Hagmann, 1994). The fanya juu retain water rather than dispose of it thereby improving moisture conditions down slope, excess water is discharged slowly and contains very little sediments. Less land is taken away from production compared to standard contour ridges. The channel occupies approximately 1–1.5 m compared to the standard contour ridges which take up to 3 m, therefore the fanya juu only takes about 7% land out of production while the standard contour takes about 15% (Dreyer, 1997). The channel depth is usually 50–60 cm with cross-ties at 10 m intervals. The channel can be graded (pegged at a specified gradient) (graded fanya juu) or on a dead level contour (zero gradient) (level fanya juu) depending on how dry the region is and the water retention requirement. Their labour requirement depends on slopes, time of the year and rockiness of the area.

2.6. Routine measurements

Each site had 4 water harvesting treatments which were replicated 3 times. The analysed variables included soil profile water content and crop grain yield data. Maize was planted 0.5 m from the water harvesting structures, on both upslope and downslope positions. Soil profile water content was measured using a gravimetric method. Soil samples were collected from 1 m upslope and at 1, 2 and 6 m downslope of each structure. Soil water content was measured from soil samples collected from the 0–15 and 15–30 cm depths at least once every month during the growing season. Rainfall was measured at each site using standard raingauges. Crop yields were assessed on both downslope and upslope of each water conservation structure. Yield mesurements were collected from 10 m^2 plots (2 m × 5 m), 1 m upslope of the water harvesting structures and at 2 andat ˜6 m downslope of the water harvesting structures.

2.7. Statistical analysis

Variations in soil water content and yields were analysed using analysis of variance (ANOVA). Data analysis was carried out using combined analysis of variance across site using Genstat Statistical package (SNV 2011).

Table 2
Average volumetric and profile moisture content for all the study sites. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pits, SC = Standard contour. Lsd = least significant difference.

	Volumetric moisture content (%)	Profile moisture content (%)
CRCT	5.5	8.3
FJ	5.4	8.2
IF	5.4	8.1
SC	5.2	7.8
LSD	0.25	0.38

Lsd = least significant difference.

3. Results

3.1. Soil and profile moisture content

Soil profile moisture contents were controlled by rainfall events. Average rainfall for the 3 sites were 500 mm per annum (Fig. 1). The rainfall varied with season but was not significantly different among sites. The soils at the study sites were sandy and derived from granitic parent material. The soils had an effective depth that was < 70 cm. Soil moisture content was significantly different among treatments and varied significantly between season (years). Over the three cropping seasons, there was no significant treatment differences in soil moisture among sites, and depths. Volumetric water content did not vary with depth, and was 5.3 for the 0–15 cm depth compared to 5.4 for the 15–30 cm depth. However, the average soil profile moisture and profile moisture contents was signficantly different among treatments (Table 2).

The corresponding profile mositure content was also not significantly different between depths, and was 8.0% for the 0–15 cm depthand 8.2% for the 15–30 cm depth. Throughout the cropping season, improved water harvesting technologies maintained higher moisture content compared to the SC, and this was more apparent during the dry spells that occurred in February and March when crops were silking and grain filling.

3.2. Slope position

There were significant differences in volumetric water content for treatments which were located upslope, middle slope and lower slope. The average soil moisture content across treatments were 5.1, 5.3 and 5.3% for upslope, middle slope and lower slope respectively. For the different treatments the upslope had lower moisture content (Table 3). There were also no significant slope, depth interactions that were shown. However, among the improved water harvesting techniques, CRCT had the highest soil moisture content.

3.3. Effects of distance from the water harvesting structure

Soil moisture content was highest closer to the water harvesting structure, and decreased with increasing distance from the structures.

Table 3
Average soil moisture contents in water harvesting structures located in different slope positions. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pits, SC = Standard contour.

	Lower slope	Middle slope	upslope
CRCT	5.6(0.29)	5.6(0.28)	5.3(0.28)
FJ	5.4(0.29)	5.5(0.29)	5.2(0.29)
IF	5.2(0.29)	5.2(0.28)	5.2(0.28)
SC	5.0(0.29)	5.0(0.29)	5.0(0.29)

The figure in parethesis shows the standard error.

Table 4
Effects of distance and depth on volumetric and profile water content. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pits, SC = Standard contour.

	vmc		pmc	
Distance	0–15	15–30	0–15	15–30
1 m (upslope)	5.6(0.2)	5.8(0.2)	8.4(0.29)	8.8(0.29)
1 m (downslope)	5.7(0.19)	5.8(0.2)	8.5(0.29)	8.8(0.29)
2 m (downslope)	5.1(0.2)	5.2(0.2)	7.6(0.30)	7.8(0.31)
6 m (downslope)	5.1(0.2)	5.3(0.2)	7.6(0.3)	8.0(0.31)

vmc = volumtric water content, pmc = profile moisture content. The figure in parethesis shows the standard error.

Average mositure content were significantly higher in 1 m from the water harvesteing structure compared to the 2 m and 6 m. However, soil moisture at 2 m from the water harvesting structure were not significantly higher than the 6 m. The volumetric water varied with depth, and also with distance from the water harvesting structures (Table 4). The volumetric moisture content for the 0–15 and 15–30 cm depths were comparable. The volumetric moisture content and profile moisture content did not vary with depth for different treatments (Table 4). However, the volumetric water content varied with increasing distance from the water harvesting structures and soil moisture was significantly higher 1 m from the water harvesting structure compared to 2 and 6 m from the water harvesting structure. However as distanc from the structures increased to 6 m, there were no significant differences in both profile and volumetric water content (Table 5). Volumetric and profile water content maintained significantly higher levels in the water harvesting structures compared to standard contours.

3.4. Effects of the different water harvest technologies on maize yields

The average maize yield across sites and cropping seasons were 1156, 1129 and 985 kg ha^{-1} for Kuchicha, Mukandabvute and Takarasima respectively. The yields varied significantly with season, and were lowest in the 2004/5 season across all farmers (Fig. 2). During the 2004/05 and 2005/06 cropping season, the highest maize yields were at Mukandabvute and least at Kuchicha. However, Kuchicha had the highest maize yields during the 2006/07 (Fig. 2). The average maize yield varied signifcantly with water harvesting technology and were 1196, 1164, 1250 and 749 kg ha^{-1} for CRCT, FJ, IF and SC respectively (Fig. 3). Improved water harvesting technologies had significantly higher yields compared to SC (Fig. 3). However, there were no significant differences in maize yields among the improved water harvesting technologies (CRCT, FJ and IF).

Across the three cropping seasons, the 2004/2005 season had the lowest maize yields. Maize yields during the 2004/2005 season were not significantly different between treatments, sites. In 2005/2006 and 2006/2007, the improved water harvesting technologies had higher maize yields compared to SC. In 2005/2006, Mukandabvute had higher yields compared to the other improved water harvesting technologies. In 2006/2007, Kuchicha had the highest maize yields compared to the other sites, and the CRCT water harvesting technology had the highest yields though it was not significantly different from IF (Fig. 4).

Maize yields varied significantly between slope positions and were higher in the lower slope compared to the middle and upper slope, which were not significantly different. However, there were significant differences in maize yields between improved water harvesting technologies (CRCT, FJ and IF) and SC, (Fig. 5). Maize yields for the improved water harvesting structures were signifcantly higher than the SC at different distances from the water harvesting structures. Maize yields did not vary significantly with distance from the improved water harvesting structures except for FJ were there was a decrease in yields as the distance increased. However, among the improved water harvesting structures, maize yields were significantly lower for the CRCT compared to the FJ and IF at 1 m (upslope) and at 2 and 6 m downslope. There as a good correlation between water content and maize yields (R^2 = 0.80), and this suggested that soil moisture played a very significant role in determining maize yields (Fig. 6).

4. Discussions

In Zimbabwe there is high variability in rainfall from region to region and from year to year. Only 37% of the country receives adequate rainfall for rain-fed agriculture, while rainfall is insufficient, erratic and unreliable for the rest of the country. In Zimbabwe rainfall exhibits high degree of inter-annual variability and several droughts have been recorded from 1959 to 2002. During this period Zimbabwe has experienced 15 droughts occurring on average, every 2 to 3 years (World Bank, 2009). To worsen the situation, the recent climate change phenomenon has resulted in increased temperatures, and a further decrease in rainfall in the dry areas (Natural regions IV and V) of Zimbabwe (Mugandani et al., 2012), such as the south east and southern part of the country, where models have predicted decrease in agricultural productivity and maize yields of between 15% and 35% by 2030 (Cline, 2007; IPCC et al., 2007; Lobell et al., 2008; New et al., 2006).

The risk and vulnerability of most smallholder farmers is increased because most of the agricultural systems in Zimbabwe are predominantly rain-fed (Camberlin et al., 2009; FAO, 2000). Hence, these challenges that are associated with climate change, signal an urgent need for modified farming systems to allow smallholder farmers to adapt to changing climate. Examples of modified farming systems include the use of rain water harvesting to supplement rain-fed smallholder farming systems in ASAL which are characterized by frequent droughts.

The use of CRCT, FJ and IF, represents innovative and sustainable climate change adaptation strategy than can be used in semi-arid regions to improve dry-land crop production. Contours ridges are found in all fields throughout the semi-arid regions of Zimbabwe and they dispose off the little rainfall which is the principal water resource for agriculture from the fields (Nyamadzawo et al., 2013). Most of the rainfall received in semi-arid regions is lost as runoff, with none to very little being harvested in field so that it can be used for future plant growth. The modified tied contours systems retains water in-field which

Table 5
Changes in soil moisture content with increasing distance for the different water conservation structures. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pits, SC = Standard contour.

	%vmc					pmc			
	1 m (up)	1 m (dn)		2 m (dn)	6 m (dn)	1 m(up)	1 m (dn)	2 m(dn)	6 m(dn)
CRCT	5.9	5.8	5.5	5.1		8.7	8.8	8.2	7.6
FJ	5.9	6.0	5.1	5.0		9.0	9.0	7.8	7.7
IF	5.8	5.8	4.8	5.0		8.7	8.7	7.2	7.5
SC	5.5	5.5	5.2	5.2		8.1	8.1	7.7	7.7

vmc = volumtric water content, pmc = profile moisture content. up = upslope, dn = downslope.

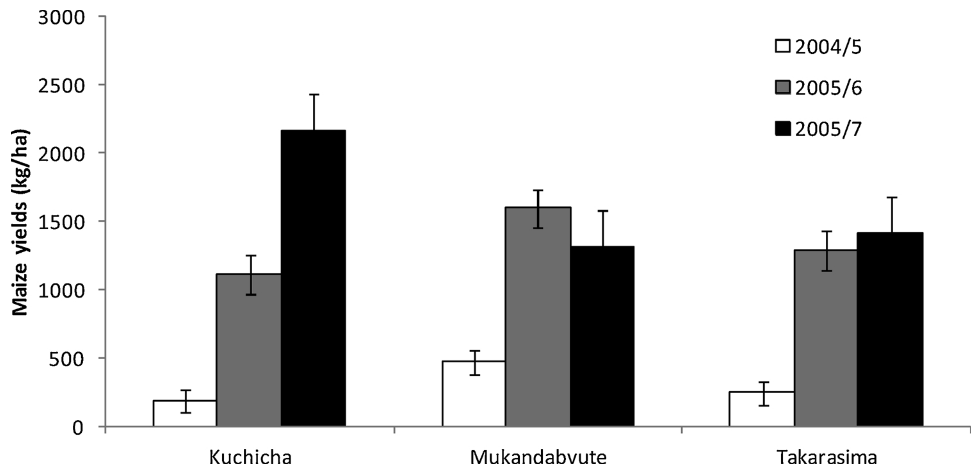

Fig. 3. Average maize yields across sites for the 3 seasons, 2004/5, 2005/6 and 2006/7. Vertical bars are error bars with standard error.

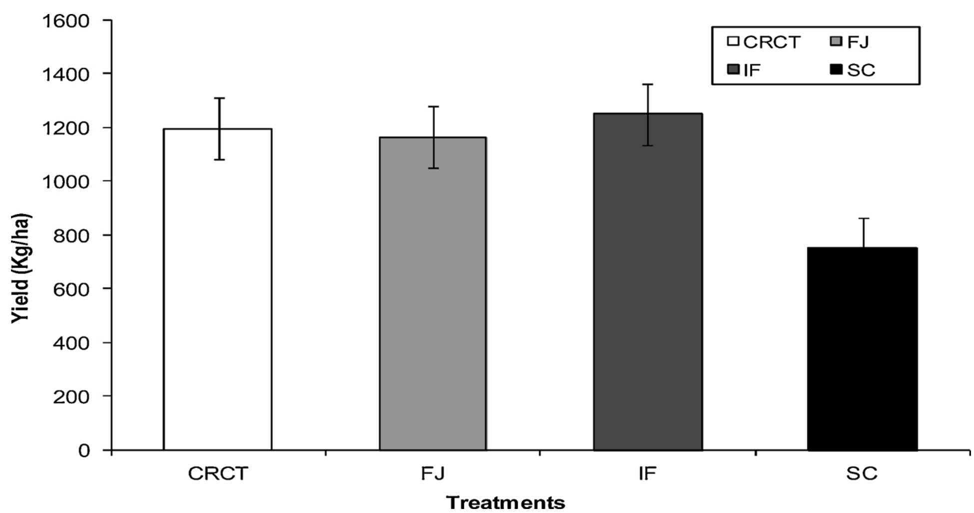

Fig. 4. Average maize yields across the different water harvesting technologies for the three cropping seasons. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pit, SC = Standard contour.

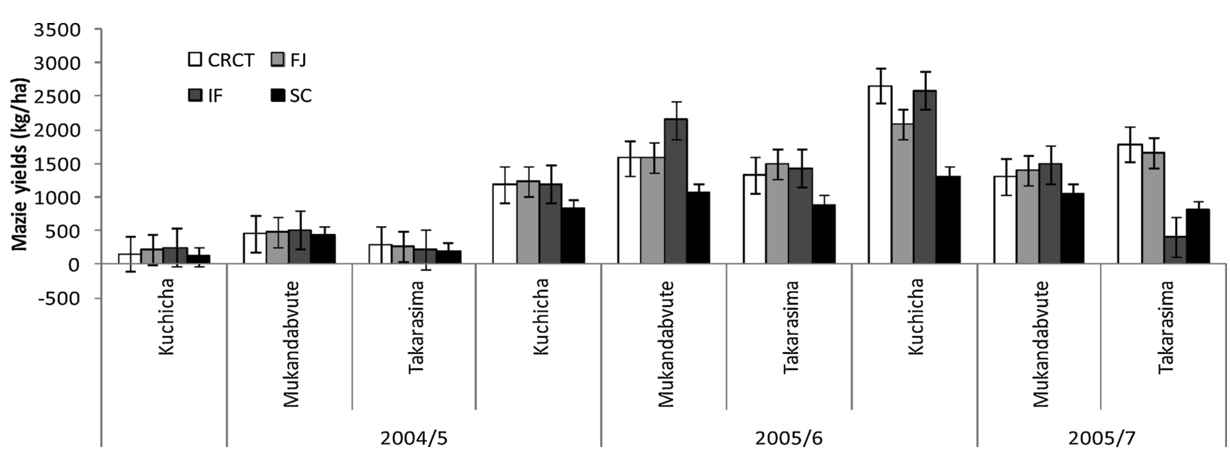

Fig. 5. Maize yields across farmer sites, and seasons for the different water harvesting technologies. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pits, SC = Standard contour. Vertical bars are error bars with standard errors. Lsd = 252 for both season, and farmer treatment interaction and 437 for farmer season treatment interaction.

can sustains crop production even during dry spells (Dreyer, 1997; Nyamadzawo et al., 2015) and this can reduce crop failures and may ultimately lead to improved household food security compared to standard contours.

In semi-arid regions such as Chivi in Masvingo water harvesting technologies such as infiltration pits have been widely adopted (Hagmann, 1994; Maseko, 1995; Mutekwa et al., 2005; 2006). These studies suggest that in-field water harvesting improves water use efficiency and is a potential climatic change adaptation strategy in semi-arid regions. Hence the optimization of the rainfall management

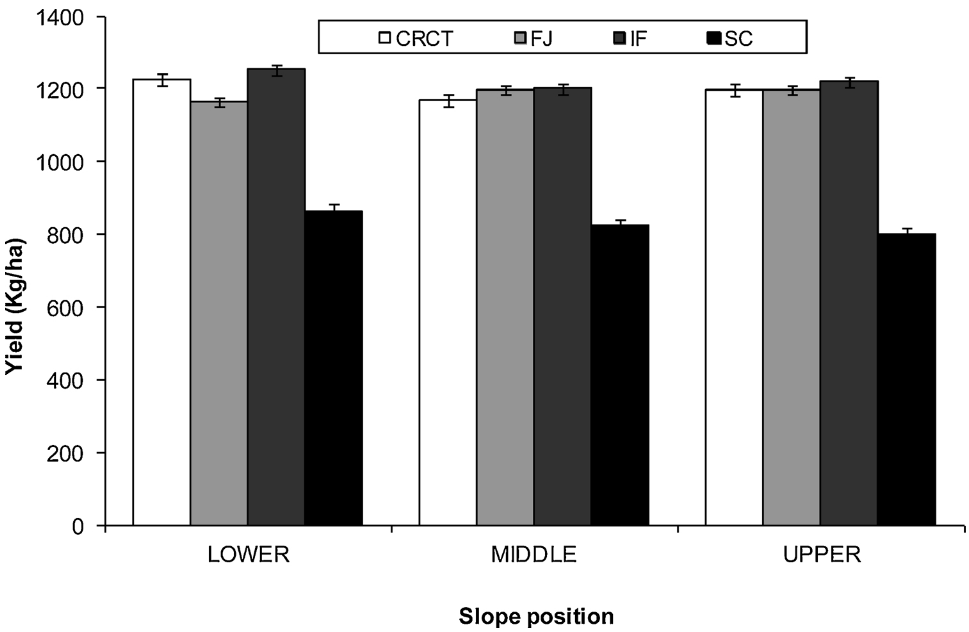

Fig. 6. Maize yields as affected by slope position. CRCT = contour ridges with cross-ties, FJ = Fanya Juu, IF = graded contour reinforced with infiltration pits, SC = Standard contour. Vertical bars are error bars with standard errors. Lsd = 252 for both season, and farmer treatment interaction and 437 for farmer season treatment interaction.

through water harvesting is sustainable and when integrated with the use of improved/ hybrid seeds, and inorganic and inorganic manures there is a potential for improved rain fed agricultural production (Ibraimo and Munguambe, 2007; Nyagumbo et al. 2009).

Improved water harvesting technologies resulted in higher soil moisture contents than SC and similar results were also reported by Mugabe (2004); Munamati and Nyagumbo (2010) and Gumbo et al. (2012). Moisture content will increase as the water harvesting structure can hold water and give it ample time to infiltrate, thus improving ground water recharge and ensuring enough water is stored in the soil profile for plant use. Although the average volumetric water contents between the improved water harvetsing structures and the SC was not so large, tose small differences in soil water content are critical especially during importat stages of crop growth such as tillering and silking. The volumetric moisture contents during the months of February and March when crops were silking and grain filling was significantly higher under improved water harvesting structures compared to the SC. Such small differences in moisture contents can result in significant differences in maize yields between improved water harvesting structures and SC.

Soil moisture content however, varied as distance from the water harvesting structure or contour ridge increased. However, there were no significant differences in moisture between in upslope and downslope positions. Though this study did not quantify soil moisture on the upslope, of the structures we studied, we expected that soil moisture content would be greater downslope as reported in studies by Mugabe, 2004 who reported that water harvesting structures replenished soil water on both upslope and downslope sides, though the lower side had higher soil moisture content. The strength of using water harvesting structure is that they retain water in-field, and the moisture spread to a greater distance from the water harvesting structures. However, the optimum distance where the maize would benefit from the moisture retained in the water harvesting structures was not very apparent a maximum of 6 m was evaluated.

Maize yields were significantly different among water harvesting technologies when compared to SC. Similar studies reporting higher maize yield under improved water harvesting systems compared to SC were reported by Gumbo et al. (2012) and Nyamadzawo et al. (2015). This shows that there is a great potential to improved crop yields, food security and livelihood among households using infield water harvesting. However, maize yields varied with study site, and were comparable for Kuchicha and Mukandabvute, which were significantly higher than Takarasima. Variations in yields can be attributed to several factors among them; differences in soil types, inherent soil fertility, management and variations in rainfall amounts and distribution between sites. Maize yields also varied with sloe positions, and yield were signiificantly higher in the lower slope compared to the middle and upslope position. This could be attributed to several factors among them higher soil moisture content, and soil fertility as eroded soil is deposited downslope.

Although in-field water harvesting techniques are beneficial in semi to arid lands, adoption by farmers has been poor because of several reason, such as lack of knowledge, high labour intensity, for example, Ibraimo and Munguambe (2007) estimated that, the cost of making tie ridges was 33% higher than conventional land preparation using hand hoes. Hence, there is need to increase extension activities to improve uptake of these technologies by farmers. However, the comparative advantage of contour based technologies such as CRCT and infiltration pits is that they require less labour because they utilize standard contour ridges that are already in place in Zimbabwe. In Zimbabwe every field has a contour ridge as these were enforced as part of conservation measures of the Land Husbandry act of 1951. The same sentiments were also echoed by Hagmann and Murwira (1996) who reported that farmers in semi-arid showed more interest in large, semi permanent to permanent water harvesting structures as they save labour in the long term. Permanent water harvesting technologies like CRCT are likely to be well received by farmers and current extension effort should promote such technologies in ASAL.

Currently few studies have been carried to evaluate the performance of structures such as IF and CRCT. As a result current recommendations for water harvesting technologies give blanket recommendations and do not consider inherent differences in soil water holding capacities, soil depth and texture. Hence, there is need to carry out research on site specific water harvesting technologies across a range of soils so that we can recommend the best technology for each soil type. For this study, the soils were mainly sandy and they had an effective depth that was < 70 cm. This effectively meant the less water can be stored in the soil, hence there is need to retain and store as much water as possible.

5. Conclusions

The use of improved infield water harvesting structures has a great

potential to improve maize yields in ASAL. Improved water harvesting strategies improved water retention compared to SC which were designed to dispose off water. The use of CRCT, FJ and IF can be an important and sustainable adaptation strategy to climate change in ASAL as the maize yields were better than SC. Maize yields varied across treatments, with season and with sites, and this can be attributed to variation in soil types, soil fertility, farmer management and in rainfall amounts and distribution between sites. However, we could not asceratin with the best water harvesting technology from this study. More work should be done to carry out site specific evaluation of these in-field water harvesting technologies as they may not work across all soil types. Though contour based water harvesting structures are a among potential solutions chllenges of water shortages in the smallholder farming sector, the major challenges in using these include labour shortages, lack of technical knowhow and poor extension and research initiatives. Improved water harvesting structure are not a pancea to the challenges of climate change and should be integrated with other adaptation strategies such as early planting, and drought tolarent varieties, improved soil fertility management to name a few.

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Appendix A. Supplementary data

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